COMPARATIVE ANALYSIS OF CEMENT-SAND MORTAR AND GEOPOLYMER MORTAR UNDER FIRE

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Abstract- Fire hazard is the most common hazard and causes a significant reduction in physical and mechanical properties. Under high temperatures, the structural integrity of conventional cement mortar decreases drastically. Along with that, the dependency of the construction industry on cement should be reduced and alternatives must be considered as the production of cement requires a high rate of fuel consumption with excessive CO_2 emissions. Geopolymer is an emerging alternative binder to cement as it is more sustainable. In addition, it has superior fire resistive properties due to its in-organic polymeric nature. In this paper, cement-sand and geopolymer mortar was prepared and a comparative analysis was performed by observing the residual physio-mechanical properties after exposure at elevated temperatures. It was observed after performing various tests that the physical and mechanical strength of cement-sand mortar specimens were found to be extremely affected in contrast to geopolymer mortar. This study focused on the fire-resistive approach of geopolymer composite as compared to cement composites, in order to consider it as a surrogate to conventional cement in the future.

Keywords- Cement mortar, Fire hazard, Geopolymer mortar, Residual Strength.

1 Introduction

Fire incidents can be due to various reasons. It has an impact on human life and also damages the physical structure of the buildings. The intensity of the fire blazes affects the structure accordingly. In conventional cement structures, fire causes damage due to the difference in thermal characteristics between aggregate, cement, and steel, which results in the development of pore pressure and thermal stresses with the decomposition of cement hydration products as well. Cracking and spalling start at 300°C and 1200°C respectively. At sufficiently high temperatures, hydration products started to decompose and cause a reduction in materials' mechanical strength [1]. To increase the sustainability of our structure against fire, we need to integrate such materials that have significant fire-resistive properties and can enhance the residual strength of the structure as compared to cement composites. Secondly, there is also a need to reduce the dependencyof our industry on cement composites because of its high fuel consumption for its production. Cement production contributes about 7% of total CO_2 production worldwide. One ton of cement produces almost one ton of CO_2 emission during its synthesis [2].

Precursors involved in the synthesis of geopolymer are mostly raw materials like calcinated clays, coal ashes, and slag. Fly ash (FA) is a waste or by-product of coal and in accordance with ASTM C618-19, a low calcium compound containing FA (Class F) can be used for the preparation of alkaline activated geopolymer. Recent studies have also shown that potassium hydroxide (KOH) containing composites have better fire-resisting properties than NaOH [4]. Alkaline activators are considered to be binders in geopolymer and will be the reason for the reaction between the precursors and activators resulting in achieving material strength. Alkaline-activated geopolymers have better fire resisting properties and are more stable than conventional ceramic composites. At high temperatures, the strength of the geopolymer increases because of the geopolymerization process i.e., the geopolymer matrix stabilizesdue to a further increase in the temperature or heat

because it is accelerating the reaction [3]. Geopolymers are in-combustible because of their inorganic polymeric nature, and they have high endothermic properties because of the presence of physically and chemically bonded water. That is why they are capable of absorbing heat. Thermal conductivity varies between 0.1-0.3 W/m-K which is less compared to other materials hence it can work as a flux barrier. The thermal resistance value of geopolymer is comparable to fire-resistive materials [1].

Through this background, our goal is to introduce geopolymer mortar as a surrogate for conventional cement mortar because it possesses superior fire-resistive properties with high residual strength. This work is designed to observe the comparative performance of geopolymer mortar as compared to cement-sand mortar at elevated temperatures.

2 Experimental Procedures

Cube molds of dimension 70mm x 70mm x 70mm were taken and considered to be the desired shape for the given experiment. Molds were cleaned and oiled properly a day before the sample casting. Geopolymer and cement-sand mixtures were prepared according to the defined ratios and then samples were cast, by placing the mixtures in the oiled mold specimens. The detailed experimental procedure is explained below:

2.1 Material

Low calcium containing Class F FA, according to ASTM C618-19 is used as the main precursor for the preparation of geopolymer, as shown in Table 1. FA contains rich alumina-silica compounds, which play a role in achieving better strength because the more the alumina-silica compounds, the more the alkaline reaction takes place. Lawrencepur sand is used as a filler in geopolymer mortar preparation. Alkaline activators used are; 14 molar KOH solution and sodium silicate (Na_2SiO_3) solution. Whereas DG cement and Lawrencepur sand were used for the preparation of conventional cement mortar.

Table 1: Specifications of Class F FA according to ASTM C618-19

Properties	FA Classes	
	Class F	Class C
Silicon Dioxide (SiO2) + Aluminum Oxide (Al2O3) + Iron Oxide (Fe2O3), min %	70.0	50.5
Sulphur Trioxide (SO3), min %	5.0	5.0
Moisture Content, min %	3.0	3.0
Loss on ignition	6.0	6.0

2.2 Mortar Synthesis

Geopolymer and cement-sand mortar were prepared according to the mix design ratios as described in Table 2. For the preparation of geopolymer mortar, alkaline activators were used in liquid form so, a solution of 14M KOH was prepared a day prior to the mortar synthesis. Firstly, FA and sand were taken according to given ratios and dry mixed together. After that, both liquids were mixedand added slowly into the dry mix. Gently mixed with an electrical mixer while adding liquids to the dry materials evenly, to form a uniform paste. Similarly, in the case of cement-sand mortar, the required amount of cement, sand, and water was taken according to the defined ratios (Table 2). Water was added to the dry mix to form a uniform paste. The mix design ratio for geopolymer and cement-sand mortar preparations is shown in Table 2.

Table 2: Mix design ratios for the preparation of mortars

Geopolymer Mortar	Ratios	Cement-sand Mortar	Ratios
Alkaline activator/Precursor	1:3	C/S	1:3
FA/Sand	1:1	W/C	1:2
KOH/Na_2SiO_3	2.5		

2.3 Specimen Casting

Cube specimens (70 mm) were cast by placing the prepared mixtures of both geopolymer and cement-sand mortar in the oiled molds. Molds were cleaned and oiled properly a day before the sample casting. In the case of cement-sand mortar, the prepared mix was poured in three different layers into the cube mold. While pouring into the molds, each layer was tampered with a tamping rod 25 times each timeto remove the voids. After that, molds were placed on a vibration table for further compaction. Similarly, in the case of geopolymer mortar, the prepared mix was immediately placed into the molds as the setting time of geopolymer is very quick.

Curing conditions plays an important role to achieve the strength of the casted specimens. For cement-sand mortar, samples were cured at room temperature for 27 days while the geopolymer specimens were placed in an oven at 90 – 110℃ for 24 hours as geopolymer mortar gains strength at high temperature because the rate of initial alkaline reaction increases at high temperature. After oven curing, samples were placed at room temperature to gain further strength.

2.4 Exposure conditions and testing

Mortar specimens were prepared and cured for 28 days, according to their condition. Cured specimens were then placed in a furnace over for 120 minutes at elevated temperatures (400℃, 600℃, and 800℃). A number of specimens of both mortars at each temperature are shown in Table 3. Experimental tests were then performed on cooled specimens, by placing them under different tests for the comparative analysis of fire-resistive properties. Both mechanical and physical tests including compressive strength, crack pattern, and crack width were performed, and observations were made in order to observe the damage or the effect of high temperature on residual strength properties of specimens.

Table 3: Exposure conditions for both geopolymer and cement-sand mortar

Sr #	Temperature (°C)	Time Duration (minutes)	Number of specimens
1	20	120	3
2	400	120	3
3	600	120	3
4	800	120	3

3 Research Methodology

In order to introduce a material having better fire-resisting properties and can be used as an alternative to cement, experimental research is important. In order to do the comparison, twelve cube specimens of both geopolymer and cement-sand mortar were cast according to the fixed ratios. Samples were then cured according to their required conditions in order to achieve full material strength. When reached their 27-day strength, samples were then placed in an oven for thermal exposure, at elevated temperatures (400℃, 600℃, and 800℃) for two hours. After thermal treatment, cube specimens are allowed to cool down properly. Experimental tests were then performed on cooled specimens, by placing them under different tests for the comparative analysis of fire-resistive properties. Both mechanical and physical tests including compressive strength, crack pattern, and crack width were performed and observations were made in order to observe the damage or the effect of high temperature on residual strength properties of specimens.

4 Results

Mechanical and physical properties of both geopolymer and cement-sand mortar were observed by performing different experimental tests including residual compressive strength test, maximum crack width, and crack pattern as well. Samples were placed under observation when they properly cooled down after the thermal exposure in the furnace for the required time. Three specimens of both mortars were placed at each temperature for 120 minutes. Following is a detailed discussion on experimental observations.

4.1 Compressive Strength

Average residual compressive strength of both geopolymer and cement-sand mortars were taken and then the representative graphs were made to show the comparison properties of the effect of thermal exposure on compressive strength. Figure 1 shows that cement specimens have maximum strength at room temperature and then show a decreasing trend from 24.3MPa to 2.7MPa, with the increase in temperature. But in the case of geopolymer mortar, there is a slight difference in compressive strength of geopolymer at room temperature and after thermal exposure at 400 ℃. This shows that geopolymer mortar has maximum strength at 400 ℃ because with the increase in temperature, the rate of geopolymerization increases. After 400 ℃, there is a bit decreases in compressive strength after the initial stability. At 800℃, compressive strength further decreases to 24.9MPa as shown in Figure 1.

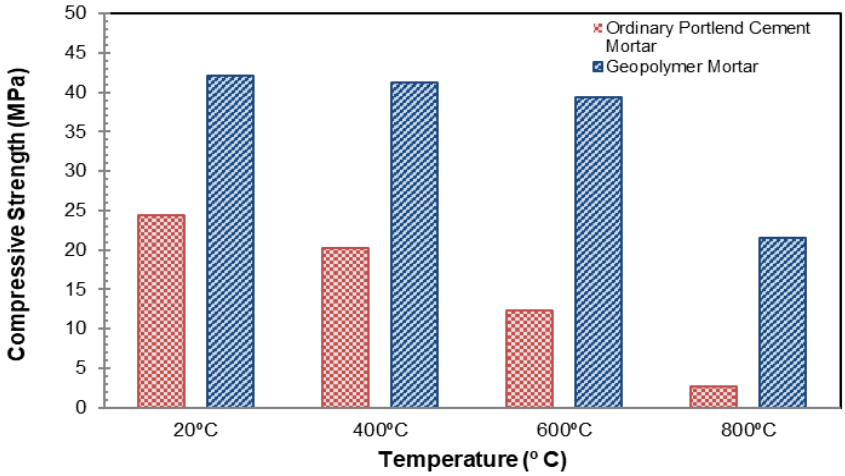
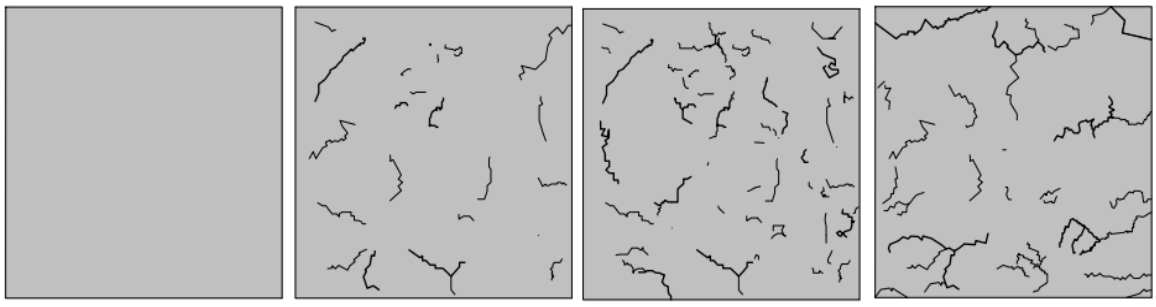


Figure 1: Influence of temperature on compressive strength of geopolymer and cement-sand mortar

4.2 Cracking Pattern

The cracking pattern of each cube specimen was visually observed from the specimen after exposure to the conditions.To observe the effect of thermal treatment on the physical properties of OCM specimens, crack pattern of samples at each temperature was drawn simply by visualizing without using any equipment. To enhance the crack pattern, the J-image effect of every specimen oneach temperature was made. From the enhanced image, the crack pattern was drawn to create a schematic diagram by using Autodesk AutoCAD 2018.

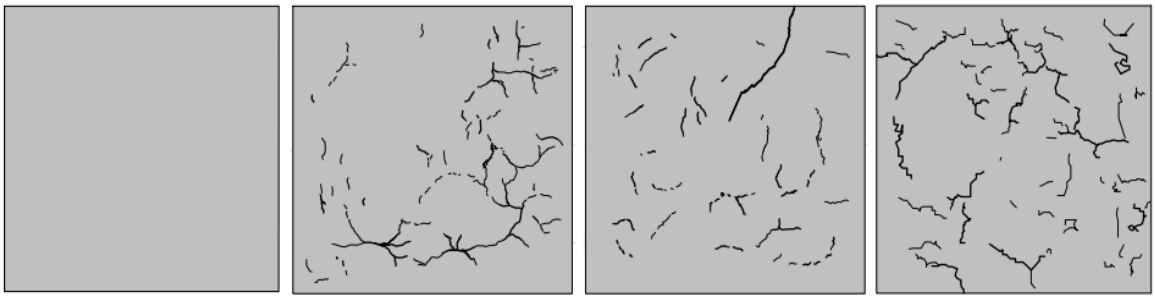


(a) 20 °C (b) 400°C (c) 600°C (d) 800°C

Figure 2: Schematic image representing influence of temperature on crack pattern of cement-sand mortar

Crack pattern of cement mortar specimens at each temperature are shown in Figure 2. Schematic diagram shows that with the increase in temperature, the number of cracks in cement mortar specimen increases.

Cracks in cement mortar is mainly due to thermal expansion and pore pressure build-up. At 100°C, free water starts evaporating causing weight loss, after 100°C up to 300 °C, dehydration of chemically bounded water occurs resulting into increase in number of cracks [1]. And further increase in temperature also damages the strength, as a result at 800 °C, the corners of cement specimens were also damaged (Figure 3). But in case of geopolymer specimens at 600 °C having less cracks as compared to specimens at 400 °C. This is because at 400 °C, excessive shrinkage occurred due to the evaporation of chemically and physically bounded water. And at 600 °C, the geopolymer gel started melting and filling the gaps [5, 6]. But further increase in temperature from 700 °C, crack pattern in geopolymer increases.



(a) 20 °C (b) 400°C (c) 600°C (d) 800°C

Figure. 3: Schematic image representing influence of temperature on crack pattern of geopolymer mortar

3.3 Maximum Crack Width

Cube specimens prepared from both mortars were placed under a microscope to observe the maximum crack width. Three samples at each temperature were taken and the lens was adjusted on the scale as well as on the crack of maximum width. The crack width of all the specimens was taken in mm. And graph was made by taking an average of two nearby values of maximum crack width as shown in Figure 4. No cracks were found in both mortars at room temperature but with the temperature increasing from 400°C to 800°C, the maximum crack width in cement-sand mortar also increased. Maximum crack width shows an increasing trend and the maximum crack width value in the case of cement-sand mortar is 800°C. But in geopolymer mortar, crack width even at 200°C was greater in comparison to cement-sand mortar. It is evident from the graph that its value shows a drastic increase at 600°C and the maximum value is recorded at 600°C which is 0.06mm because there is more drying shrinkage as more chemically bound and physically attached water with the hydroxyl group as well is present in geopolymer mortar as compared to cement mortar [1]. This value is greater than the maximum crack width at 800°C. It is shown in Figure 4 that the further increase in temperature from 600°C causes a decrease in maximum crack width. This is because, all water evaporates at 600°C, and after that geopolymer gel starts melting and filling the cracks [5, 6]. This is the reason at high temperatures or under fire, the maximum crack widths in the case of geopolymer are less as compared to cement-sand mortar.

(a) Geopolymer Mortar (b) Cement-sand Mortar

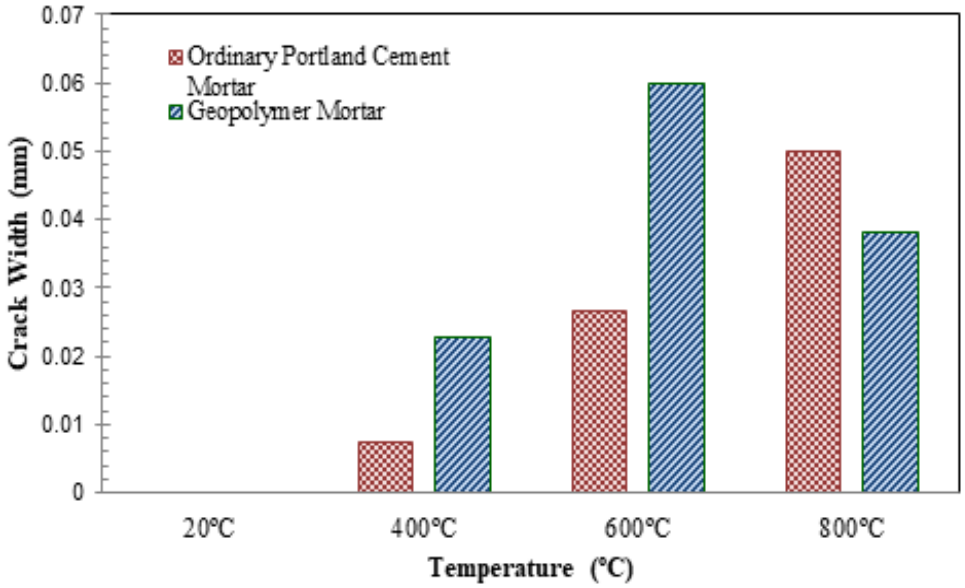


Figure 4: Influence of temperature on maximum crack width of geopolymer and cement mortar

5 Practical Implementation

As geopolymer mortar has better fire resistance and high residual thermal properties as compared to cement-sand mortar. To enhance the sustainability and lifespan of our structures, we should integrate geopolymer mortar in areas that are more sensitive to catching fire. Ceramic composites should be replaced with geopolymer mortar in those areas which are more vulnerable to fire hazards. In order to avoid direct damage to the structural integrity of buildings, geopolymer mortar lining should be applied in areas like (tunnels, basements parking, kitchen areas, compacted apartments, etc.) as passive protection.

6 Conclusion

Experimental analysis of this research concludes that the specimen prepared from geopolymer mortar has high residual compressive strength, less porosity, and crack width as compared to conventional cement-sand mortar even at elevated temperatures. The crack width of geopolymer mortar started to decrease with the increase in temperature, as the polymeric gel filled the gap and strengthen the mortar specimen. Edges of cement-sand cube specimens started to damage from 600°C while geopolymer specimens remain un-damaged even at 800°C.

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